Characterization for High Dynamic Range Imaging

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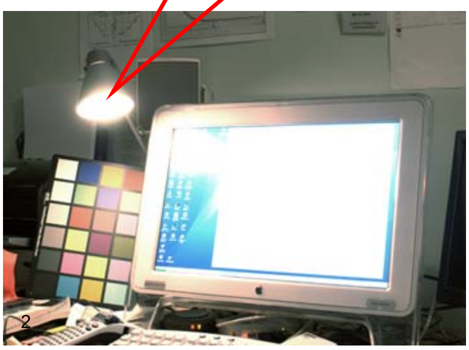
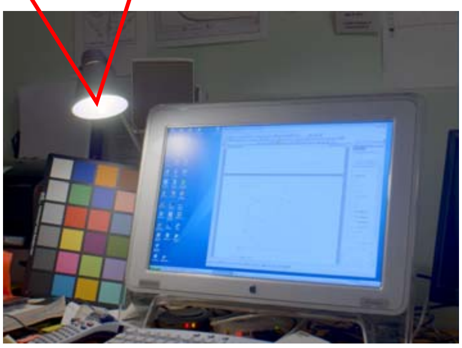
Introduction

- Proposal: a simple HDR acquisition technique, *HDR characterization*
- Photos at the high dynamic range (HDR) imaging…
- Meaning of the pixel information of HDR images?
- Resolving the limit of dynamic range of imaging hardware
- So far: no real meaning of values – are just ratios
    - Achieve accurate measurement of absolute luminance and color

LDR (255,255,255)

HDR (10304.20,10752.58,10688.10)



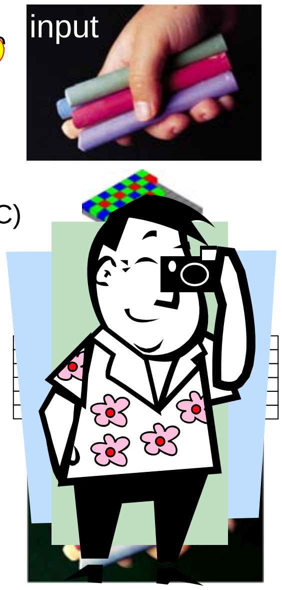


Background: Color Imaging Workflow

Scene Radiance

Energy in electr…

Device-dependent



Energy ↓ Camera's Color Matching Function ≈ Human Eye's CMF

Amplifying & Quantization of voltage

Analogue-to-Digital Converter (ADC)

Limited dynamic range

Dig.Vol. ↓

Demosaic & De-noising

Interp… …B channels

Non-linear response

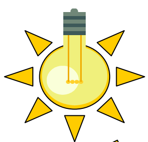
Adaptation

Gamma correction → $\gamma = 2.2$

White Balancing

Camera Output (file or display)

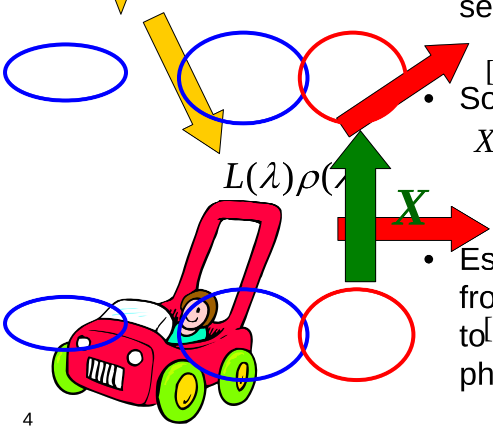
Background: Characterization

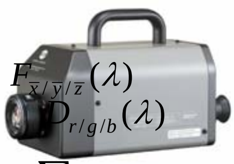


$L(\lambda)$

$L(\lambda)\rho(\lambda)$

X





- Charact… …a linear transfor… …matching function $F_{\bar{x}/\bar{y}/\bar{z}}(\lambda)$ …amera sensitivi… $D_{r/g/b}(\lambda)$

$$[\vec{x}, \vec{y}, \vec{z}] = \sum_{\lambda} L(\lambda)\rho(\lambda)F_{\bar{x}/\bar{y}/\bar{z}}(\lambda)\Delta\lambda$$

- Solve linear equation:

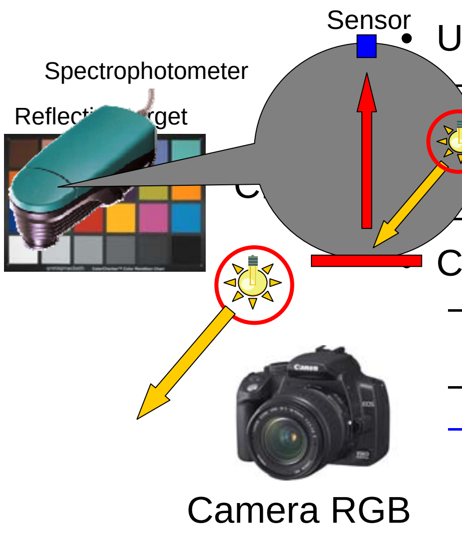
$$X = \left(A^T A\right)^{-1} A^T M$$

$$A = [\vec{r}, \vec{g}, \vec{b}],\ M = [\vec{x}, \vec{y}, \vec{z}]$$

- Establish… …on model from traini… to convert new images into physically meaningful values

$$[\vec{r}, \vec{g}, \vec{b}] = \sum_{\lambda} L(\lambda)\rho(\lambda)D_{r/g/b}(\lambda)\Delta\lambda$$

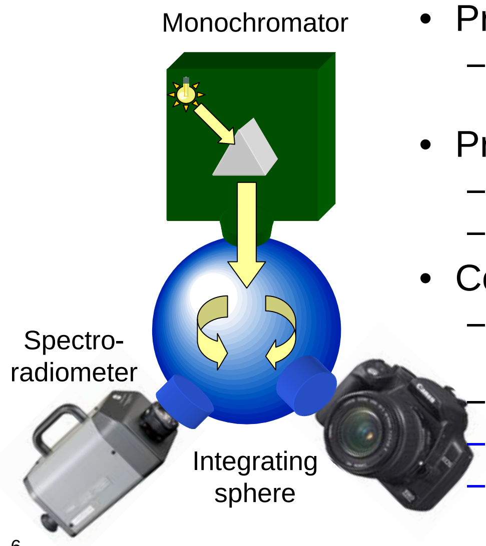
Previous Work: Reflectance-based*



- Uses:
  - Spectrophotometer
- Pros:
  - Easy to use
  - Cheapest cost
- Cons:
  - Characterize only color (not absolute luminance)
  - Only for LDR
  - Limited to known illumination (light source spectrum needs to be measured or fixed)

* [PAJ,01;MJ,02;Joh,02;ISO,06; ICC,04;GHS,01]

Previous Work: Monochromator-based*



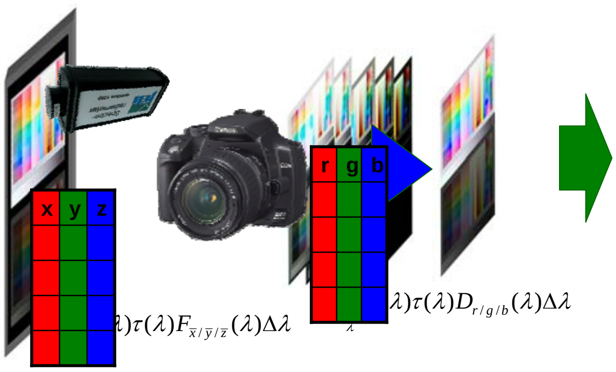
- Procedure:
  - Derive actual basis functions for cameras (400-700nm)
- Pros:
  - Rather accurate
  - Supports metameristic colors
- Cons:
  - Characterize only color (not absolute luminance)
  - Only for LDR
  - Expensive devices
  - Complicated calibration of the devices

* [MVPC00,MJ02,MVPC03,ISO06,NFG07]

Our Goals: HDR Characterization

- Optimized for HDR imaging
  - Wider color gamut and high dynamic range
- Practical
  - Easy to use
  - Time-efficient
- High accuracy
  - Characterize not only color but absolute luminance
  - Ideally as accurate as spectroradiometer
    (which measures the spectrum of incident light)

Pipeline to Build a Characterization Model



Build a characterization model per camera

$$A = [\vec{r}, \vec{g}, \vec{b}],$$
$$M = [\vec{x}, \vec{y}, \vec{z}]$$
$$X = \left(A^T A\right)^{-1} A^T M$$

1. Measure physical radiance from the HDR reference target (using a spectroradiometer)
2. Assemble a HDR image from raw CCD responses
3. Build a model from HDR camera responses to radiance measurements in least square sense

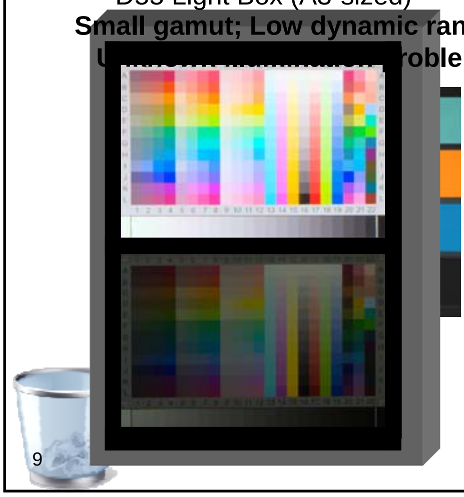
HDR Reference Target

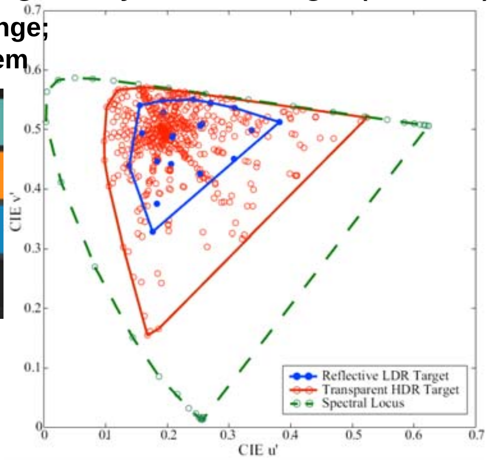
- Transparent target with wider gamut & higher dynamic range (4.5:2.0)

D55 Light Box (A3-sized)

Small gamut; Low dynamic range;

...roblem



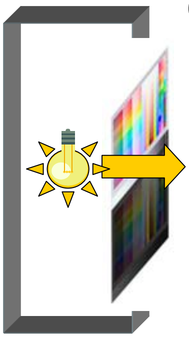


Measurement Geometry

- We support unknown illumination conditions:

$L(\lambda)$

0-180° Geometry

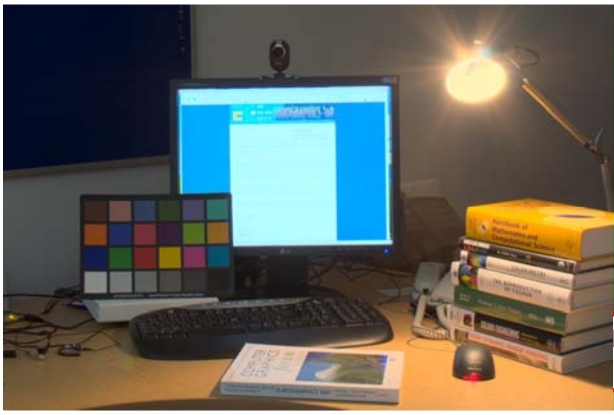


radiant power $\Phi(\lambda) = L(\lambda)\tau(\lambda)$

$$\sum_{\lambda} \Phi(\lambda) F_{\bar{x}/\bar{y}/\bar{z}}(\lambda)\Delta\lambda$$

$$\sum_{\lambda} \Phi(\lambda) D_{r/g/b}(\lambda)\Delta\lambda$$

Using Model with New Test Images



- [illegible: overlapping slide text] (sRGB,D65) with tone-mapping [RSSF,SIG02]

Before & After


Difference map (mid-gray = mean, amplified by 10)

- Before: or
  - No physi ation
- After: cha
  - Contains

Experimental Training/Test

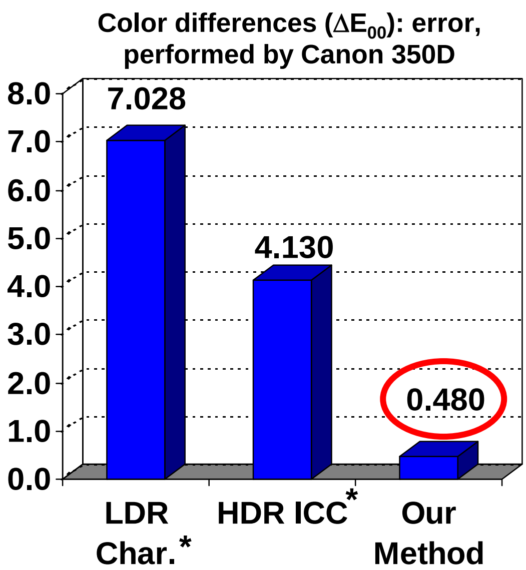
- Trained models from three different cameras:

- Test characterization models under different illuminations of high dynamic range:
  - Training: D55 illuminant
  - Test: Tungsten (with/wo IR filter), Fluorescent, etc…

Example of Test Set

- Compare the characterization and radiometric measurements
- Compute Color Difference (Euclidean Dist.):
  - CIE ΔE_{00}, CIE u'v', CIEXYZ (absolute)

Overall Results of Accuracy



- Training set: under 5571K Illumin. [2556 cd/sm²]

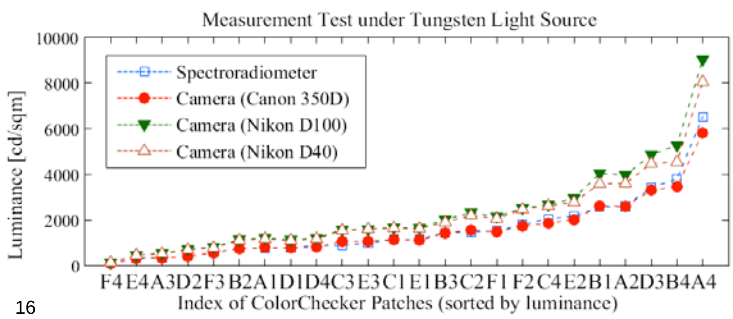
→Test set: under 2946K Illumin. [6508 cd/sm²]

- Significant accuracy even under different illumination

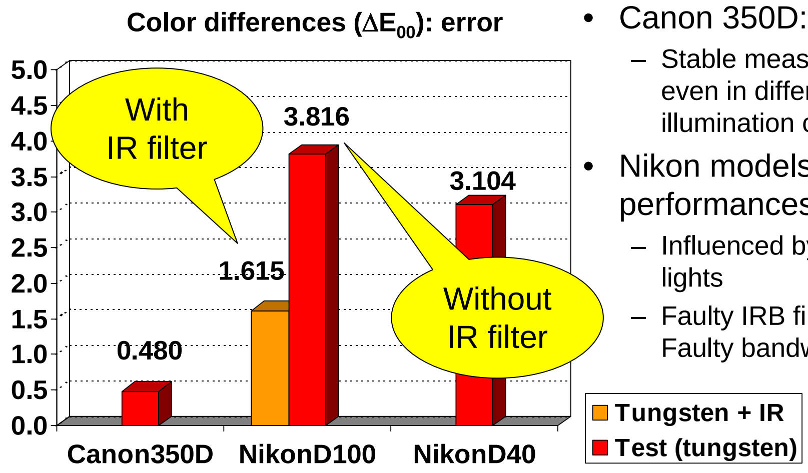
*[ICC,04; GHS,CIC01]

Results: Absolute Luminance Accuracy

- Absolute luminance difference
  - Between *HDR imaging (camera)* and *spectroradiometer*
- Canon 350D:
  - Very similar performance to the spectroradiometer
- Nikon D100 & D40:
  - Higher level luminance (due to Nikons' engineering problem)



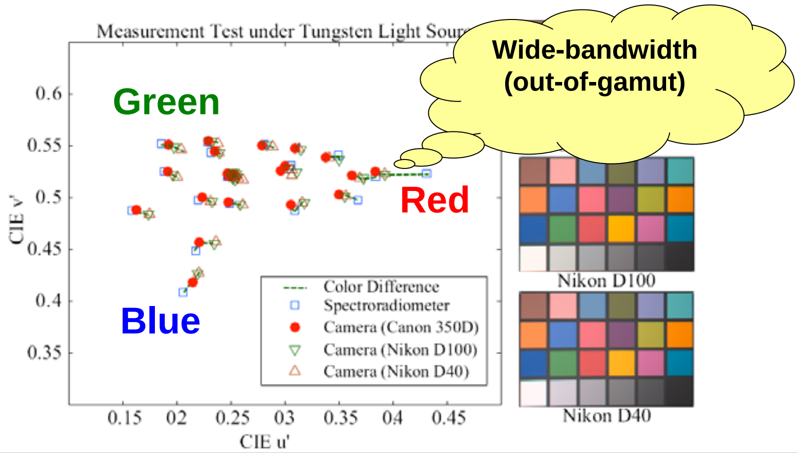
Results: Accuracy by Cameras



- Canon 350D:
  - Stable measurement even in different illumination condition
- Nikon models performances:
  - Influenced by infrared lights
  - Faulty IRB filter or Faulty bandwidth

Results: Chromatic Accuracy

- Chromaticity difference:
  - Canon 350D provides high accuracy of chromaticity measurement (except in highly saturated red)



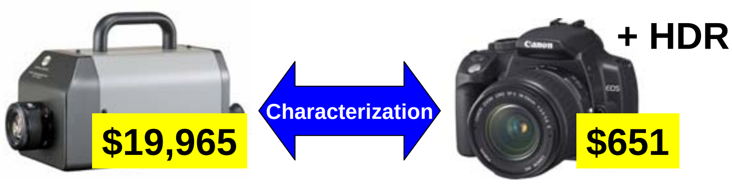
Discussions

- Performance of characterization depends on:
  - Optical quality of digital cameras
  - Engineering limits: Infrared blocking filter, camera bandwidth
  - Lens flare, veiling glare, vignetting: not taken into account

- Potential measurement errors with *metameristic colors*
  - Like other target-based models

Conclusion

- A simple and accurate technique:
  - Characterize HDR imaging systems
  - In terms of absolute luminance and color (radiance at every pixel)
- More accurate
  - Than reflectance-based characterization methods
  - Applicable even in unknown illumination condition



Point measurement of radiance

Image measurement of radiance at every pixel

The End

Thank you very much
for your attention!

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